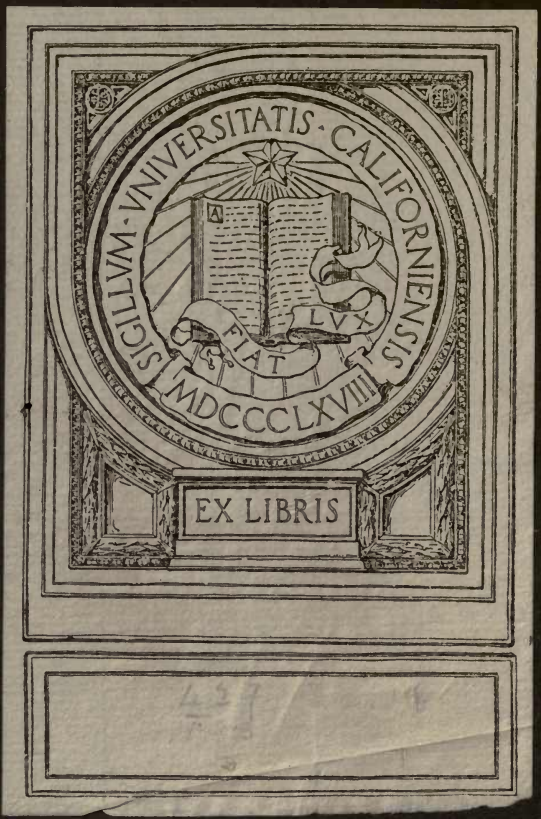
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SIGNAL SERVICE NOTES NO. XII.

THE SPECIAL

CHARACTERISTICS OF TORNADOES,

WITH PRACTICAL DIRECTIONS FOR THE PROTECTION OF LIFE AND PROPERTY.

PREPARED UNDER THE DIRECTION OF
BRIG. & BVT. MAJ. GEN'L W. B. HAZEN,
CHIEF SIGNAL OFFICER OF THE ARMY,

BY

JOHN P. FINLEY,
SERGEANT, SIGNAL CORPS, U. S. ARMY.

BY AUTHORITY OF THE SECRETARY OF WAR

WASHINGTON CITY:
SIGNAL OFFICE.
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CONTENTS.

THE SPECIAL CHARACTERISTICS OF TORNADOES.

The present pamphlet considers the practical bearing of some of the results of the study of tornadoes, and will answer questions as to the object of this systematic labor under government authority and the possibility of deriving any benefit from the knowledge obtained by scientists.

I.—TERMS.

In the United States, the terms cyclone, tornado, and hurricane, are frequently interchanged in ordinary conversation and, in the minds of nine-tenths of the people, these terms mean one and the same thing. This is not altogether surprising, considering the want of systematic instruction in *accurate* meteorological knowledge, and the general disposition of intelligent minds to speculate about the weather. But, in fact, the tornado of the United States is a well-defined species of storm, differing in many points from hurricanes, cyclones, and thunder-storms, and it is the only one that will now be considered.

II.—TORNADOES.

Omitting consideration of the tornadoes, so called by Portuguese and Spanish navigators on the African coast, and confining our attention to the United States, it is believed that these storms are possessed of the following prominent characteristics: The general direction of movement of the tornado is invariably from a point in the southwest quadrant to a point in the northeast quadrant. The tornado cloud assumes the form of a funnel, the small end drawing near to, or resting upon, the earth. This cloud and the air beneath it revolve about a central vertical axis, with inconceivable rapidity, and always in a direction contrary to the movement of the hands of a watch. The destructive violence of the storm is sometimes confined to a path a few yards in width, as when the small or tail end just touches the earth; while, on the other hand, as the body of the cloud lowers, more of it rests upon the earth, the violence increases, and the path widens to the extreme limit of eighty rods. The tornado, with hardly an exception, occurs in the afternoon, just after the hottest part of the day. The hour of greatest frequency is between 3 and 4 p. m. Tornadoes very rarely, if ever, begin after 6 p. m. A tornado *commencing* about 5 p. m. may *continue* its characteristic violence until nearly 8 p. m., which means, only, that the tornado cloud may be *travelling* after 6 p. m., or after 7 p. m., but it does not *develop*, that is, make its appearance, for the first time after those hours. Outside of the area of destruction, at times even along the immediate edge, the smallest objects often remain undisturbed, although, at a few yards distant, the largest and strongest buildings are crushed to pieces. At any point along the storm's path, where there is opportunity afforded the tornado cloud to display its power, the disposition of the debris presents unmistakable signs of an action of the wind, such as might be called a rotation, from the right through the front to the left around the centre. The destructive power of the wind increases steadily from the circumference of the storm to its centre.

Observations with a single isolated barometer will not indicate the approach of a tornado, however near the position of the instrument to the path of the storm, but

such observations are of value when a number are displayed upon the daily weather map. The tornado season is embraced between the 1st of April and the 1st of September. The months of greatest frequency are June and July. There are, however, instances in a long series of years where tornadoes have been reported in every month of the year. Taking the whole United States together, it is found that the region of greatest average frequency per year, per square mile, embraces the following states: Georgia, Illinois, Indiana, Iowa, Kansas, Missouri, Ohio. The actual figures are about as given in the following table:

Relative frequency of tornadoes. 1874 *to* 1880, *inclusive.*

State.	Area in units of 10,000 square miles.	Average number per year for each state.	Average number per year for each 10,000 square miles.
Alabama	6.8	1.5	0.30
Arkansas	5.2	1.0	0.20
Connecticut	0.5	0.2	0.40
Georgia	5.8	3.6	0.62
Illinois	5.5	6.2	1.13
Indiana	3.4	3.0	0.88
Iowa	5.5	3.2	0.58
Kansas	8.1	6.9	0.85
Louisiana	4.1	1.4	0.34
Massachusetts	0.8	0.9	1.12
Michigan	5.6	1.6	0.29
Minnesota	8.4	2.6	0.31
Mississippi	4.7	1.1	0.23
Missouri	6.5	5.0	0.77
Nebraska	7.6	1.8	0.24
New Hampshire	7.9	0.4	0.44
New Jersey	0.8	0.6	0.75
New York	4.7	2.5	0.53
North Carolina	5.1	1.8	0.35
Ohio	4.0	2.6	0.64
Pennsylvania	4.6	1.9	0.46
South Carolina	3.4	1.6	0.47
Tennessee	4.6	1.9	0.41
Wisconsin	1.0	0.2	0.20
Vermont	5.3	1.4	0.26
All of New England	6.8	2.1	0.31

It is not within the province of this memoir to discuss at length the points of difference or harmony, or enter into an intricate analysis of meteorological phenomena and the multiform operations of atmospheric changes attending the origin, development, and complete formation, of tornadoes. On the contrary, it is desired to present a minute consideration of the peculiarities of tornadoes, with a view to placing at the disposal of the people most interested the facts and practical results of past and present investigations of this terrible, yet most interesting, class of storms.

III.—CONDITIONS OF FORMATION.

These may be divided into classes as follows:

First: those within the reach of, and which may be known or investigated by, an isolated observer. To the single observer, located at his farm, workshop, or store, there are important atmospheric conditions which he may carefully watch and study with profit, viz.: the gradual setting in and prolonged movement of the air from the north and south points; the gradual, but continued, *fall* of the thermometer during the prevalence of the former currents, and a *rise* during the predominence of the latter.

If the northerly currents are the prevailing air movements at the place of observation, the atmospheric disturbance is forming southward, but, if the prevailing air currents are from the south, then to the northward of the observer.

Carefully study cloud development, color as well as form; also, manner and direction of approach. Clouds render visible the air currents, and are full of meaning.

A study of the currents of the atmosphere would be impossible without their existence, and that, too, in a variety of forms. Dispense with cloud formation, and the face of the sky would become blank, and severe storms no longer visible.

Wind direction, temperature, and clouds, are proper subjects of observation and investigation by the isolated observer. The barometer is of less importance in this line of inquiry, unless the barometric observations can be promptly compared with those taken at other points near by and at the same moment of time. The tornado itself is an extremely local affair, and the accompanying barometer changes do not affect a large extent of country. Probably if a barometer were placed in the immediate track of the tornado cloud, it would not, with any certainty, indicate the presence of the storm until the crashing winds had fallen upon the instrument.

Second: conditions that can only be witnessed and analyzed by the intelligent eye of the student of the Weather Map.

From this panoramic view of the situation a vast extent of country can be most carefully watched from hour to hour, for days, weeks, or months. Atmospheric conditions on opposite sides of the probable course of the storm can be watched from their inception, and, in any new relations, easily detected and analyzed. From a study of the Weather Map, it has been found that the formation of what is termed a barometric trough or elongated area of low pressure (where the barometer stands below the normal for that region and for the hour of observation) precedes the occurrence of tornadoes in the lower Mississippi valley, or adjoining states to the south and east. This low pressure area assumes the form of an ellipse, and generally extends from southwest to northwest between northern Texas and the upper lake region. Such a depression may lie between the central Mississippi valley and the lower lake region, trending northward just south of Michigan and over the Ohio valley. The longer axis of either of these depressions is easily estimated, while the shorter axis may be stated as generally varying from three to five hundred miles. To the north of the longer axis, even for a distance of several hundred miles, the winds are found to proceed from any or all points between northeast and northwest with comparatively low temperatures, accompanied sometimes by a cold rain or even snow. South of the longer axis, and generally to a greater distance, the winds come from any or all points between southeast and southwest, accompanied by comparatively high temperature, high humidty, and often dashes of quite heavy rain.

As these conditions continue to prevail, the map shows an increasing contrast of temperature on the north and south sides of the longer axis, and as this contrast of temperature gradient increases, the formation of clouds commences in earnest.

An isolated observer in the warm south wind on the south side of the longer axis of course can know nothing of the existence of this cold, dry air to the north of him, but he sees huge masses of clouds of dark and portentous appearance bank up in the northwest and southwest with amazing rapidity, and soon the scene becomes one of awful grandeur.

The upper currents of air are thus indicated by the cloud formations. The condensation of vapor increases rapidly, and huge volumes of air rush upward. The outward indication of the formation of a tornado is first shown in the whirling, dashing clouds over the broken surface of the heavy bank of condensed vapor forming the background; a scene not easily depicted or realized by one who has not witnessed it, but never to be effaced from the memory of the actual observer. The next stage in the further development of this atmospheric disturbance is the gradual descent of

the funnel-shaped cloud. The tornado is now before us, not fully developed, but soon to acquire that condition.

IV.—PREMONITORY SIGNS.

On the day of the storm, and for several hours previous to the appearance of the tornado cloud, what indications of its probable formation and approach are within the comprehension of an ordinary observer and can readily be detected by him? A sultry, oppressive condition of the atmosphere, described by various observers as follows: "I really experienced a sickly sensation under the influence of the sun's rays." "I was compelled to stop work on account of the peculiar exhaustion experienced from physical exertion." "It seemed as if the lightest garments that I could put on were a burden to me." "There was not a breath of air stirring." "The air, at times, came in puffs, as from a heated furnace." "I felt a want of breath, the air frequently appearing too rarified to breathe freely." "I was startled at the sudden and continued rise in the thermometer, especially at this season of the year." "It was terribly oppressive; it seemed as if the atmosphere was unusually heavy and pressing down on me with a great weight."

Enough examples have now been cited to indicate the effects and signs of this oppressive sultriness. Other signs may be found in the development and peculiar formation of the clouds in the western horizon. Sometimes these peculiar clouds extend from the southwest through the west by the north to the northeast. More frequently, however; they form in the northwest and southwest, sometimes commencing, first in the former quarter and then again in the latter, but in either case they are equally significant. The marked peculiarity of the clouds is found to occur not only in the *form* but in the *color* and *character* of development.

The sudden appearance of ominous clouds, first in the southwest and then almost immediately in the northwest or northeast (or perhaps reversed in the order of their appearance), generally attracts the attention of the most casual observer. In almost all cases these premonitory clouds are unlike any ordinary formation. If they are light their appearance resembles smoke issuing from a burning building or straw stack, rolling upward in fantastic shapes to great heights; sometimes they are like a fine mist, or quite white like fog or steam. Some persons describe these light clouds as at times apparently iridescent or glowing, as if a pale whitish light issued from their irregular surfaces. If the premonitory clouds are dark and present a deep greenish hue, this fairly forbodes very great evil. So, also, if they appear jet black from the centre to circumference, or if this deep set color appears only at the centre, gradually diminishing in intensity as the outer edges of the cloud or bank of clouds are approached. Sometimes these dark clouds, instead of appearing in solid and heavy masses, roll up lightly but still intensely black, like the smoke from an engine or locomotive burning soft coal. They have been described as of a purple or bluish tinge, or at times possessed of a strange lividness, or frequently dark green, and again of an inky blackness that fairly startles you with its intensity.

The following are extracts from reports of observers: "They were the worst looking clouds I ever saw; perfectly awful." "The clouds seemed to be boiling up like muddy water, the upper surface of the cloud reminding me of the incessant eddies or whirls seen in the muddiest portions of the Missouri river." "I saw two whirling circles of lightish gray clouds in the west; they were acting independent of each other, and moved slowly inward toward each other from opposite directions. The clouds were very low; seemed to be on the earth, the wind in contrary directions across the face of the western sky, and surrounding clouds in great confusion." "Observed clouds moving in all directions; some of a dark green color, others white as steam." "The lower end of the cloud was very white, like fog." "I saw

a great smoke, and supposed, at first, it was a fire." "I saw a terrible cloud, of a dark purplish color." "There was a peculiar and terrifying look to the clouds." "I saw a green cloud in the northwest, surrounded by others not so deep set in color. Under the cloud from the southwest, there came a large number of little thunder-heads, some very dark, but others as white as steam. They seemed to be separated and running very low. I never saw clouds so low before. Pretty soon they began to go in all directions, some up, some down, right and left, backwards and forwards. I next saw a cloud that looked even all over in color and very white, the edges being pretty regular. It moved remarkably steady, and seemed to be right under the edge of the cloud from the southwest." "I noticed a strange action in the clouds, and saw a cloud rolling on the ground coming from the southwest." "The ground was covered with white, steamy looking clouds, that prevented one from seeing any distance." "Two clouds, one from the northwest, and the other from the southwest, seemed to meet, and, after meeting, passed still lower. Above their place of meeting, black smoke appeared in very peculiar shape." "The air presented a very peculiar appearance; it seemed to be in different shaded strata and quite marked." "At the bottom of the cloud a hazy appearance rose up, obstructing the view," "Two clouds came together; one from the southwest and the other from the northwest; the latter was the higher, and the former the heavier and looked the worse." "A heavy cloud spread out before us to a width of about six hundred feet, and as black as night."

The peculiarities of the clouds while they are forming is another interesting and significant feature which should be carefully watched. Under ordinary circumstances, clouds form, move, and disappear, without exciting special remark or, perhaps, thought, from the casual or even the interested observer. In the event of a thunder-storm or hail-storm, the movement and disposition of the clouds are not looked upon with fear or as possibly possessed of a power to create great havoc, but on the occasion of a tornado the formation and movement of the clouds strike most persons dumb with fear. There seems to be some strange connection between the almost simultaneous appearance of clouds in the southwest and northwest, possessing, as they do, such unusually threatening forms. As they approach from opposite directions, they are suddenly thrown into the greatest confusion, breaking up, as it were, into small portions, which dash pell-mell over each other and in every direction, now darting toward the earth, now rushing upward to considerable heights or at moderate elevations, rolling over each other in a well developed whirl. An observer, in describing the approach of the clouds from the southwest and northwest, stated that they "came together with a terrific crash, as if thrown from the mouths of cannons." Generally, following closely upon the existence of this condition, the funnel-shaped tornado cloud appears against the western sky, moving boldly to the front from without this confused mass of flying clouds. As the tornado cloud advances, these clouds continue to play about its top and sides, constituting a characteristic feature of the scene.

Another and invariable sign of the tornado's approach is a heavy roaring, which augments in intensity as the tornado cloud advances. This roaring is compared to the passage of a heavily loaded freight train moving over a bridge or through a deep pass or tunnel, or as heard on damp mornings when the sound is very clear and loud. At times the roaring has been so violent that persons have compared it to the simultaneous "rush of 10,000 trains of cars." Again, the roaring is likened to the low rumbling of distant thunder. The varying intensity of the roar, as here represented, is apparently due to the lack of uniformity in the positions of the various observers with respect to the advancing tornado cloud. Those situated nearest the cloud, other things being equal, experience the loudest roar, while to those at greater distances the noise is proportionally weaker. In any event, however, the

noise is sufficiently peculiar and distinct to create alarm, and as a means of *warning* should not be overlooked under any pretext.

V.—CHARACTER OF TORNADO CLOUD AND ATTENDING MOTIONS.

The tornado cloud is, generally speaking, at its first formation, funnel-shaped, that is to say, it tapers from the top downward, not always in the same degree with every appearance of the cloud, but the lower end of it (the part nearest the earth) is invariably the smallest, and this, too, whatever may be the inclination of the central axis of the cloud to the vertical or plumb line. As seen in different positions and stages of development by various observers, located differently, the tornado cloud has been called "balloon-shaped;" "basket-shaped;" "egg-shaped;" trailing on the ground like the tail of an enormous kite;" "of bulbous form;" "like an elephant's trunk;" &c., &c. In the majority of instances, however, observers describe the cloud as appearing like an upright funnel. When the small end of the cloud just reaches to the earth, the violence of its whirl causes a peculiarly formed cloud of dust, and finely divided debris, around which play small gatherings of condensed vapor. To all appearances now, the tornado cloud has two heads, one on the surface of the earth and the other in the sky, the bodies of each joining in mid-air and tapering both ways with the smallest diameter at their junction. In other words, the cloud now assumes the shape of an hour-glass, and the lower portion displays extraordinary destructive violence. This last and most fatal form of the tornado cloud is fortunately not a constant feature of the storm. The tornado cloud is constantly changing from the hour-glass form to that of the upright funnel, or some other intermediate shape previously referred to.

The various gradations of form, not any of which, however, affect the stereotyped relation between the size of top and bottom, number some twenty-five or thirty, so far as reliable information has been secured upon this point. These variations of form depend upon the peculiar movements of the whirling currents of air within and about the tornado cloud, the direction of the currents being outlined to the eye by the singular disposition of the rapidly condensing masses of vapor. The characteristic motions of the tornado cloud number four, and are described as follows:

No. 1. is called the *whirling* or *gyratory* motion of the tornado, which is invariably from the right by the front around to the left. This whirling motion, in all probability, exists in the air preceding the formation of the tornado cloud, and should, therefore, be placed first in order of consideration. Its velocity is far in excess of any of the others. Many efforts have been made, but most of them altogether fruitless, to estimate this velocity, and results, ranging from 100 to 800 and even 1,000 miles per hour, have been deduced, but no great precision can be assigned to such figures. In the majority of instances the determinations have ranged between 100 and 500 miles per hour. Theoretical velocities of over 2,000 miles per hour, based upon certain assumed atmospheric conditions, have been deduced. Such velocities are mathematically possible but not meteorologically probable.

The uncertainty of the computed velocities results largely from the difficulty attending the acquirement of absolutely reliable data. In all carefully conducted investigations heretofore made, such a long time has intervened between the occurrence of the storm and the arrival of the person authorized to commence the work, that valuable and satisfactory results in this direction are precluded. It is always of prime importance to ascertain definitely what portion of a building or other object was first struck by the wind and what the configuration and inclination of the exposed surface. As a rule such determination has been rendered next to impossible by the rapidity with which devasted districts recover from the violence of the storm. This statement is a most praiseworthy and well deserved commentary

on the exemplary industry and determined spirit of the people, especially of the lower Missouri valley.

With the gyratory motion of the tornado cloud objects are drawn inward to the centre of the storm, and then carried violently upward by a spirally inward and upward motion which fairly crushes and grinds into pieces buildings, trees, and whatever else stands in the line of the advancing cloud. The spirally upward motion throws the ascending debris in a circular manner outward at the top of the tornado cloud. This debris, when beyond the central whirl of the cloud, falls to the earth, but in such a manner and so disposed as to indicate the character of the force which acted upon it.

No. II. is called the *progressive* motion of the tornado cloud taken as a whole, or the motion which determines the cloud's progress from one point to another. The rate of progressive velocity ranks next in order to the velocity of motion No. I., although it is certainly at all times far below the high degree of the latter.

The rate of progress of the tornado cloud is subject to great variability throughout the duration of any one storm. Some observers have indicated the movement by the following expressions: "All in an instant." "Gone in a moment." "Quicker than thought." "Without a moment's warning." "It moved no faster than a horse gently galloping." "I just saw what it was, and then it was all over." "Before I had time to turn about in my tracks it flashed by me." "It seemed to remain almost motionless, as if held to the ground by some mysterious force." "I shuddered, held my breath, and the monster had vanished." "It seemed to move no faster than I could run."

These estimations of velocity are not to be taken literally. The circumstances under which the impressions were received must be considered, viz.: undue excitement, or abject terror. However, the comparative results are important, and, to a certain extent, reliable. In view of them, people will at least not underestimate the awful grandeur of the panorama, or fall into the fatal mistake of encouraging a belief that the tornado is not what the united experience of all observers has portrayed it.

Such data will not answer, however, to figure on very closely, but the items, average diameter of cloud, actual time (local or standard), and measured distances, are greatly desired as a basis for accurate study. Reliable data are very difficult to obtain, especially of time. This fact should be thoroughly appreciated by observers, and every reasonable effort made by them to examine their clocks or watches upon the approach and passage of a tornado cloud. Generally speaking, it is a good habit to form, of jotting down, in some place of ready reference, the hour, day, month, and year, of notable events.

In regard to this matter of time, so far as past determinations can be valued, the progressive velocity of the tornado cloud, taken as a whole, is variously estimated at from twenty-five to seventy-five miles per hour. The former is perhaps too low and the latter quite likely too high, and, although in both instances they represent the extremes, yet either of the above velocities may have existed for short intervals. The general average is probably about forty miles per hour.

No. III. is termed the *rising* and *falling* motion of the tornado cloud, the character of which finds definition in the following expressions from various witnesses: "The top of the cloud seemed to pop up and down, and then to rush forward." "It bounded over the ground like a ball." "It was the strangest jumping and flopping object I ever saw." "At times it seemed to lash the earth in terrific fury with its huge tail." "It came along, popping up and down in a most fantastic way." "Rising up like the uncoiling of a huge rope, it cut loose from the earth and passed over us with a horrible whizzing sound." "Ever and anon it would shoot directly upward from the earth, sometimes with great rapidity, and then again quite slowly, each time dashing to the surface with renewed vigor."

It is, perhaps, clearly seen that this is a distinct motion, with striking peculiarities which define its character. Sometimes, upon the lifting of the tornado cloud from the earth, it does not again descend for a distance of several miles, at times making the return movement or descension twenty or thirty miles distant, the intervening space proving a complete blank in its track. More frequently, however, these gaps are from one to five miles in length.

While the tornado cloud is traversing the atmosphere at some considerable distance from the earth, it may reach down so low as to just skim over the tops of the highest trees; descend to a level with the roofs of buildings, simply scaling off the shingles in spots or entirely on one side, leaving the roof-boards and rafters unmoved; removing the tops of chimneys; taking out all the fans in the wheels of a windmill and leaving every portion (even the tail) of the remainder of the mill unharmed; taking off the cornice without disturbing the remainder of the roof; removing simply the top boards, or one or two of the top rails, of a fence.

The tornado cloud may, however, remain at a perfectly safe distance throughout its aerial course and where it may be seen at a great height, moving solitary and alone, like a huge balloon. While in this condition it has, not a few times, been unwittingly taken for the latter object, but the mystery and sensation were entirely dispelled when the news came in from the surrounding country of the frightful power of this now silent monster.

There is still another feature of motion No. III.: upon rising from the earth and passing through a few uncertain struggles, apparently to decide upon the final direction of movement, the tornado cloud is ultimately lost sight of in the surrounding clouds, but reappears suddenly at some point, either to descend or to remain above at a safe distance.

No IV. is called the *zigzag* motion, or swaying of the tornado cloud from side to side of a general line of progress. This motion is sometimes quite suddenly performed, but generally it is a moderately slow movement, and one that can be watched and easily identified. It seems to occur most frequently just as the tornado cloud touches the earth, as described in the preceding motion No. III., when the cloud will often diverge about an equal distance on either side of the central line of movement.

At the commencement of this motion, the tornado cloud always moves first to the left (N. N. W.) and then to the right (E. S. E.). On the return movement, the cloud may or may not cross the major axis to the right (E. S. E.). The zigzag movement from one side to the other of the central line of progressive action may continue for several miles, or it may be cut short after the first few moves.

The regularity of this peculiar action appears to be in connection with indraughts of violent currents of air from the south side of the major axis, which frequently advance (only from the left side) and give evidence of their existence by swaths or narrow paths of destruction (alternating with spaces of no damage) cut inward toward and joining with the central line or track. The tornado cloud may, upon the return movement, whether executed upon the north or south side of the major axis, fail to cross it, but upon reaching it continue onward in the central line of movement to the northeast.

The distance travelled by the tornado cloud in departing from the major axis, either to the right or left, is subject to considerable variability, ranging from forty or fifty yards to nearly as many rods. While executing this zigzag motion it very frequently happens that the tornado cloud simply skims over the earth, without manifesting its extreme violence.

VI.—ELECTRICITY.

The rain and hail which sometimes precede, and at other times follow, the tornado cloud, but always accompany the heavy clouds which form in the north and

west, is generally, but not always, attended by lightning ; sometimes by most violent manifestations and then again by occasional flashes. The most terrific displays are reported during the heavy precipitation which often occurs ten or twenty minutes after the tornado cloud has passed. Very often flashes are observed in the dark clouds which begin to rise above the western horizon an hour or more before the storm.

What relation has electricity to the formation and power of the tornado clouds? Most persons are utterly at a loss to account for the prodigious power manifested in the destructive effects of the tornado. If they make the least attempt to philosophize upon the subject, they are determined to assign the cause to some mysterious interference of electrical force. Whenever a piece of iron is bent, broken, twisted, or carried a considerable distance, a tree torn up by the roots, or clothing snatched from the body, it is attributed to electricity. The fact that lightning does not appear in the tornado cloud itself is explained away by supposing some incomprehensible modification of its usual character. There is a dogmatic predisposition to attribute everything unusual to this one member of the category of physical forces. Of course it is the easiest way to get rid of a difficult problem.

Even if electricity is present, there is no requirement of its intervention to produce the force required. It is plainly evident that the movement of a current of air at the rate of two hundred to five hundred miles per hour is sufficiently powerful to demolish the strongest buildings, lift a piece of iron or, if necessary, distort its shape.

VII.—PROTECTION OF LIFE.

How can people save their lives or avoid terrible injuries? In regard to this, much, if not everything, depends upon the manner and direction a person *moves*, together with the distance of the tornado cloud, its direction, and the kind of *motion* prevailing at the *instant* one determines upon changing his position.

We will now suppose the various conditions, and proceed to point out the necessary action in each instance. In all cases it is granted, for the sake of convenience in illustration, that you are in front, or situated directly in the line, of the advancing tornado cloud. Under these circumstances, if *progressive* motion No. II. of the cloud is prevailing and your distance from it, say, eighty rods (one-fourth mile) or more, *move* directly, and with all possible dispatch, to the *north*. Whenever this motion is prevailing, *always* run to the *north*, unless in so doing you would be obliged to cross the *entire* path of the storm. A sharp glance to the *westward* will tell you whether you are about on the *southern* edge of the probable *path* of the tornado cloud, or more to the *north*. If in the *centre* or *half way* between the *centre* and the *southern* edge, your chances are best in a direct course to the *north*. If further to the *south*, move directly and very rapidly to the *south*, bearing slightly *east*. In *no event* should you ever run directly to the *east* or *northeast*. Suppose the tornado cloud to be distant from you (W. or SW.) eighty rods (one-fourth mile) and its progressive velocity sixty miles per hour, it would advance one mile in sixty seconds, or eighty rods in fifteen seconds. Assuming the average width of the destructive path of the tornado cloud to be forty rods and your position at the centre of that path, it will be seen that you have fifteen seconds in which to reach the outer edge of the path to the *north* (a distance of twenty rods) before the tornado cloud could arrive at your location.

An extreme case has been assumed in every particular. Most persons first see the tornado cloud at a much greater distance, from one to three miles, sometimes five and even ten miles on the prairies. Of course at the unusual distance of five or ten miles you could not determine very satisfactorily its probable course, especially with regard to your buildings or the safety of your own location. Watching the approach

of the tornado cloud closely at a distance of ten miles, and from that position on and on in its eastward course until it came within a mile or so of your point of observation, would give you sufficient opportunity to predict its probable course in regard to your location. When that matter is settled satisfactorily to your judgment, *move* immediately and without further hesitation. If you wait until the tornado cloud is distant one mile, you have at least sixty seconds in which to run a distance of thirty rods, supposing that you are obliged to cover more than half of the destructive path of the storm. In an average case you will probably have between eighty and ninety seconds in which to run a distance of twenty rods. In either case it is assumed that you are prepared in every particular to *move* at the very *instant* of timely warning. Further, it is assumed that you have been watching the weather of the day and understand that a terrible storm is imminent. There is, under ordinary circumstances, no reason why you should not be so informed. A tornado cloud does not come out of a clear sky, and there are many and ample signs of its approach.

What has been said in regard to the *directions* in which persons should move when the progressive motion is prevailing will, for all practical purposes, apply to motions Nos. I. and III. With respect to motion No. IV. (the *zigzag*), the following preliminary remarks should be most carefully considered: While possessed of this motion the tornado cloud crosses from one side of the central line of movement to the other. This peculiar motion most frequently occurs just after the termination of the *rising* and *falling* motion (No. III.), so that when you see the tornado cloud descending to the earth from one of its ærial flights, you may expect the *zigzag* motion to follow. The first departure of the tornado cloud from the general path of the storm's progress is to the left or on the *north* side of the path; all departures from the general direction, whether left or right movements of the tornado cloud, are invariably executed to the *eastward*. There is no backward movement to the *west;* in the event of any departure it ultimately returns to the central line of movement. Having these points well in mind, you are prepared to act when the exigency occurs. When the departure of the tornado cloud is to the *left* and your position is at any point near the central path, *move* directly *north* with the utmost rapidity, even if the cloud is at a long distance from you. Should it chance that your distance from the cloud is reduced to twenty or forty rods, run instantly to the *south*, bearing slowly *west*. This movement will take you away from the forward and return action of the tornado cloud. Another case: Suppose your position to be the same as just given, viz.: near any point in the central line of movement, but with the tornado cloud just crossing over the line to the *south*. In this event you should move instantly and directly to the *north*, bearing slowly *west*. This movement will also, as in the case previously cited, take you away from the forward and return action of the tornado cloud.

To recapitulate in regard to tornado cloud motions and the manner of movement with respect to them: never wait until the tornado cloud is almost upon you before you move, and, remember, under no circumstances, move to the *northeast*, *east*, or *southeast*.

Many foolhardy acts have been committed (perhaps through fear and excitement or positive ignorance) by persons, which have resulted in death or terrible injuries, because they tried to run in front of the tornado cloud, thinking they could outstrip it in such a race. Others have attempted to cross the path just ahead of the advancing cloud, feeling that they could reach a safe distance on the opposite side before the funnel-shaped monster passed. In one of our late storms a person assayed this trip with two horses and a lumber wagon, confident that he could at least rush his horses across the apparently narrow path of storm which seemed to progress within such circumscribed limits; he was instantly killed, one of his horses dreadfully mangled, the other seriously injured, and the wagon a total wreck.

VIII.—PROTECTION OF PROPERTY.

What can be done to lessen, in any way, the actual damage (present or prospective) to property, especially buildings? Since it is utterly impossible to move them from the path of the advancing tornado cloud, and quite as impossible to construct any buildings strong enough to completely resist the extraordinary violence of the tornado cloud, it is equivalent to saying that you can never expect to save your buildings, a conclusion to which all thought upon the subject will, sooner or later, conform. It is advisable that, under all circumstances, you should avoid any labor *especially directed* to the construction of any buildings whatsoever, for the express purpose of resisting the violence of the tornado cloud. Build your houses, barns, and stores as you would without the *knowledge* of a tornado. Other things being equal, a *frame* building is better than a *brick* or *stone* one. The former will hold together longer, is more elastic (if you will permit the term), and persons seeking refuge within its walls are much less liable to injury. There has occasionally been evidence to show, that of all frame buildings, those constructed with a hip roof and a story and a half in height, were the best able to resist the violence of the tornado; but where there are cases reported of this class of buildings being saved, there are as many, if not more, where they were destroyed precisely as any other frame building would have been under similar circumstances.

It matters not how you construct, or of what material, if your building rises above the surface of the earth (which it must necessarily do), it thereby offers obstruction to the advance of the tornado cloud, and it will go, either from the foundation, or into kindling-wood and a distracted mass of bricks and mortar, in spite of the propagation of any theory or the possibilities of architectural skill. The narrow belt of destruction renders it practicable for a whole state, through insurance companies, to bear the loss that occurs at any one point. Cheap buildings and general insurance is the wisest policy.

IX.—BUILDING SITES.

In regard to the matter of buildings, the question may be asked whether there is not some choice in a building spot, with a view to safety from the violence of the tornado. Many persons have thought that if their house or barn were perched upon some high "divide" or on the brow of a steep decline, in fact upon any marked rise above the surrounding level, the tornado cloud would rise from the earth and pass over it. But observation seems to show that the tornado cloud pursues a general course to the northeast, without regard to the character of the earth's surface, and if buildings are in the line of its destructive path, whether upon a hill, in a valley, or within a ravine, they are liable to be subject to its violence. Western towns, as a rule, are not built upon high "divides," but more frequently sheltered between neighboring hills. The same may be said of farm buildings; it being the prevailing custom to select building spots along the low bottoms of streams, for convenience to water and timber, and for protection from the continued heavy winds that break over the open prairies. Repeated investigations have shown that buildings were destroyed with as great violence and completeness upon high lands as upon low lands, but the larger number in valleys, because of the facts above cited. In many instances the funnel cloud has passed from one ridge to another, doing damage on both, but skipping the intervening depressions; again it has followed high "divides" for several miles when they coincided with its general course of movement. Ridges and valleys are almost invariably crossed at right angles when their courses are from northwest to southeast.

X.—DUG-OUTS.

Since we cannot resist the power of the tornado, the question now suggests itself, what precautionary measures can be taken? That which remains to be done can be accomplished in an unostentatious, and quiet, but secure manner. Every man can and should construct a "dug-out" at some suitable point, within a convenient distance of his house. If a person is situated within a town or city, let him select some portion of his yard for the purpose; but if residing in the country, he will not be confined to narrow limits in the selection of a desirable location. Where a person living in a village has no yard, he must, if he has a cellar, construct a cellar-cave, as a means of protection, to be described further on. With respect to the "dug-out," in no event should the roof be other than level with the surface of the earth; in fact, it is highly desirable that the retreat should be so constructed that the ordinary surface of the earth would form the roof or covering, and that all preparation of the domicile proceed by way of excavation and supports from beneath. As to location, there is not much to be said; the most important points being: convenient distance, a high, dry place, and possible opportunities to excavate into the northern or eastern slope of a knoll or hill. In the latter instance, the entrance way would suffer less from the violence of the storm, providing, perhaps, that it did not entirely envelop your retreat, for, in that event, in the whirl of the flying debris, all sides alike would be at the mercy of the winds. Having decided upon the location, as regards your house or other buildings, prepare to sink a shaft, say four to six feet square, the entire depth of your "dug-out." From either the northern or eastern (better the former) wall of this shaft, cut out a stairway leading upward to the surface of the earth, for purposes of ingress and egress. On the side of the shaft opposite the stairway, commence the excavation for the enclosed retreat. The size of the room will, of course, depend upon how much you may at any time wish to secure from injury. Better have the excavation too large than not large enough. The slight difference in the expense of time and labor may, perhaps, be the means of saving you a great deal when you least expect it. The entire room should be below the surface of the ground a distance of at least three feet, and the overhanging roof of earth should be supported from beneath by heavy timbers, to provide against any emergency, like the dashing of heavy debris or the tramping of horses and cattle upon it.

In the event of a tornado, your retreat ("dug-out") may be entirely buried beneath huge piles of debris, therefore everything must be made as secure as possible. The entrance door should be made of the heaviest timbers and supported between casings of similar strength of construction. Arrangement should be made to secure the door by heavy fastenings. In order that ventilation may be provided for, two box spouts, squaring eight inches, should be let through the roof. The top of these spouts must be level with the surface of the ground and protected by iron gratings. Ventilation may also be provided for by openings through the upper portion of the door, and these also should be protected by iron gratings.

The "dug-out" should be large enough to contain your family and such personal effects as are considered most valuable. There are many instances where persons have lost very valuable articles, even large sums of money, from supposing that if such things were placed in securely bound trunks or boxes they would be perfectly safe. There are cases where iron-bound trunks and even iron chests (not the regular merchant's safe) especially made to secure valuable articles, have been crushed or torn to pieces and the contents scattered to the winds. A heavy safe might resist the force of the wind to the extent that it would not be broken open, but it may cost you several hundred dollars, and even then you must prepare a "dug-out" for your family. Why not expend this money, or that portion of it which is found necessary,

in preparing not only a secure refuge for your family but also sufficient room for your valuables? This "dug-out" need not prove a worthless investment, even though you do not experience a tornado. On the principle alone that "an ounce of prevention is worth a pound of cure," the outlay cannot be considered a failure. It may be used for various purposes as an out-door cellar. If it proves the means of saving a life but once in five years (your own among the number), you would hardly regret the expenditure.

There is still another kind of underground protection which can be prepared to advantage, if you are provided with a cellar, either under your house or store. Having the cellar, cut an opening (say six feet high and four feet wide) into the *west* wall. Carry the excavation to such an extent underground as to provide sufficient room for your family and valuable personal effects. The roof of this cellar-cave should be composed of at least three feet (in depth) of the undisturbed surface earth, and supported from beneath by heavy timbers. In every way it should be made as secure as the "dug-out." The provisions for ventilation may be made through the roof or entrance door, but in either case well protected by iron gratings.

XI.—PROTECTION IN CASES OF EMERGENCY.

In case you are possessed of a building that has no dug-out or cellar-cave, your best plan is to *move* from your house, or from the location where you are at the *instant* stationed, as directed in the previous sections. If not able to benefit by these directions, retreat instantly to your cellar and place yourself, face forward, against the *west* wall. This is the best position in any cellar. If, for any reason, you cannot get to the *west wall*, take your position (the next best), face forward, against the *south* wall, but as near the *southwest* corner as possible. In case the building is removed from the foundation, it will always be carried above and over you, or, if torn to pieces, the debris will be instantly removed to the eastward. *Under no circumstances, whether in a building or a cellar, take a position in a northeast room, in a northeast corner, in an east room, or against an east wall.* Remember that the tornado cloud invariably moves in a *northeasterly direction.* Persons have been instantly killed, or terribly crippled, for no other reason than that they ignorantly threw themselves in the very grasp of the monster cloud.

The rule regarding the movement to the *northeast* must be obeyed. The *northeast* quarter is a fatal position, whatever may be said about destruction to life or property in any other. If, unfortunately, you are close pressed by the advancing cloud, never remain *standing* and attempt to weather the storm, but throw yourself *prone* (face downward) upon the ground, head to the east, and arms over the head, to protect it. If you should chance to be near a large stone or stump, or some heavy, low object firmly imbedded in the ground, take a position directly to the east of it, lying prone upon the ground, head toward the object, protecting the former with your folded arms. This advice is given in the event of extreme necessity, where other and better opportunities are unavailable or have been forfeited. It is better, if possible, never to trust yourself behind or about any movable object located within the centre of the storm's path; by all means not a tree or anything that rises some distance above the surface of the ground. If you can get out, never remain in a house, or any other building that is at all likely to be torn down or removed from its foundation. If forced to remain in a building without a cellar, always take a position against the *west* or *south* wall (better the former), either prone (face downward) upon the floor or standing with your back to the wall.

In any building, always take your final position on the first or ground floor or in the cellar. Never stand or lie in front of a door or window, or near a stove or heavy piece of furniture. Make every effort to get into the *west* room and, if possible, before the onslaught, remove all furniture from the western portion. If you

have the necessary time, shut tightly every window and door in the building within which you may be located at the time of the storm.

Never take refuge in a forest, in a small grove of trees, in an orchard, in a building, or near a fence of any kind, unless such obstruction is entirely out of the line of the storm.

If possible, always open the doors of your out-buildings and let your stock loose, driving them to the north, as before directed; or, if the tornado cloud seems about to pass to the north of your buildings, your stock should be driven *southward*, the rules being, of course, the same as for human beings.

XII.—PROTECTION IN TOWNS AND CITIES.

With regard to the protection of life and property in towns and cities liable to be visited by tornadoes, what has already been suggested in the matter of *north* and *south* movements, "dug-outs," and cellar-caves, will, of course, apply here. But where a large number of persons are congregated, each intent upon his particular business, some provision should be made for the mass of inhabitants who are performing their various duties in and out of doors, and who, by reason of their peculiar situation or labor, cannot, if they would, stop to study the prognostics of the sky.

With regard to this matter a few suggestions will be offered which may not be amiss. On any day when the weather conditions presage the probable approach of a violent wind storm, it should be the duty of those in authority to deputize certain persons, one or more in each ward, the number depending upon the size of the town, to watch the character of the sky and approach of the storm, and, if a tornado, to give timely warning of its advance to the various families in their respective wards, and take charge of the removal of persons and property to places of safety. In the matter of warning the various portions of the town, it would probably be to advantage to make use of the church and school bells, by ringing them, in some peculiar manner, to be decided upon by previous arrangement and generally understood. It should be well known that the persons above referred to are possessed of special authority while performing their duties. They should be cool, brave, active, intelligent, and judicious men. They should completely understand the situation, know precisely what is needed and how to supply it. All men should appreciate the situation of these persons, and avoid confusion, by a strict compliance with orders. It will not be necessary for these persons so deputized to be adepts in the science of meteorology, or to devote their time, from the 1st of April until the 1st of September, exclusively to observations of the sky.

The signs (as before described) of tornado cloud formation and approach are distinct and sufficiently suggestive to afford opportunity for timely and concerted action. The time for action will necessarily be limited, and the watch need not commence until there is every reason to believe that such a course is absolutely necessary. No one should smile at the novelty and minuteness of this arrangement, or at the idea of employing weather guards at western towns. It is a means of precaution very competent for the protection of life and property.

XIII.—STATE WEATHER SERVICES.

The State Weather services of Ohio, Indiana, Kansas, Nebraska, Missouri, Iowa, and other states, under the efficient supervision of their several directors, are doing most excellent general meteorological work. They should receive the hearty aid and appreciation of the people and of the legislatures of their respective states. Every state should have a weather service, every township an observer, and every chief observer at the county seat be authorized to receive monthly reports from the various observers within his jurisdiction and forward the same, monthly, to the state

director of such service. Each director should have the time and force at his disposal to thoroughly digest the meteorological conditions of each and every month, throughout the year, preparing and publishing, at the termination of each month, and also at the close of each year, a general summary of atmospheric phenomena coupled with the evidence of earnest and well directed efforts toward comparative study and practical results.

Such funds as are necessary to carry forward a work of this kind should yearly be appropriated by the state legislature. As so organized, and when in working order, each state weather service should co-operate with the United States Weather Service, at Washington, and thus complete a system of meteorological work which would effect a marvelous advance in the study of this most important science.

There is no country on the face of the globe where meteorology can be studied with so much advantage, practically and scientifically, as in North America. The elementary principles of meteorology, especially in regard to storms, should be taught in every high school. In the colleges and universities an advanced course should be prescribed. Wild speculations regarding the laws of the weather are exceedingly rife, touching every branch of the science, and, in view of this, *facts* and *principles* should alone be considered in conducting the prescribed course of any educational institution.

It is not believed that in this concise presentation of important facts the results altogether meet the supreme desire, or, perhaps, the hope, of the people interested in the subject of tornadoes. Such desires or hopes may never be realized, not, at least, until the investigation and analysis of these phenomena have been perfected; yet you have before you in very brief form the results of over five years of labor and an examination of over 600 tornadoes.

XIV.—THE OBSERVATION AND RECORD OF TORNADOES.

In order to be prepared for the possible appearance of a tornado, so far, at least, as local indications are concerned, let every person situated in those regions of country where the tornado is of yearly occurrence commence to carefully observe and record the daily changes in the face of the sky, the variations of temperature, the direction of the wind, and the character and development of clouds. Not that any person should devote most or all of his time to this work of observation, nor even all of his spare time, but, for the sake of regularity and uniformity, certain hours for regular work of this nature are advised, viz: 3, 7, and 11 a. m., 3, 7, and 11 p. m., Washington time.

Should unusually interesting phenomena occur during the period between these hours of observation, it would be advisable to increase the number of observations, making these at as short intervals as the importance of the case demands. By means of these frequent observations, every feature of the storm becomes the subject of inquiry and quite probably more important results attained. For purposes of investigation of tornadoes the observations need not continue throughout the entire year, at least in the northern and western states, although such a length of record would be of great value for other purposes; but observations should certainly begin by the 1st of April and continue, unremittingly, until at least the 1st of September. Observations through the autumn can be maintained with profit.